RP461

A VACUUM TUBE AMPLIFIER FOR FEEBLE PULSES

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ABSTRACT

A resistance-capacity coupled 5-stage amplifier is described which is suitable for automatic registration of the primary ionization pulses produced when corpuscular rays pass through a shallow ionization chamber. A discussion of an improved type of ionization chamber is given.

CONTENTS

I. INTRODUCTION

It has long been recognized that a direct method of recording current pulses produced by ionizing particles, such as α or H rays, would be of great value in the study of this type of radiation. By such a procedure, in which the current pulse occurring in an ionization chamber is amplified linearly and recorded, a decided advance over the now familiar Geiger counter is achieved in that the particle is not only counted, but also the ionization which it produces as it passes through the ionization chamber is instantaneously measured and recorded. In view of the fact that an α ray passing through a chamber 5 mm in depth would produce on the average only about 10^4 ions, the rise in potential of the insulated collector of the ionization chamber can not be much greater than 10^{-4} volt for any practicable value of the capacity of the collector. The problem is therefore to amplify this potential pulse up to the order of 20 volts before applying it to the grid of the output tube of the amplifier. This is very difficult or impossible to do with ordinary radio tubes, since poor grid insulation, large grid currents, large grid capacity, and other undesirable characteristics serve to obliterate entirely the effect of the arrival of such a small charge to the grid. It is not surprising, therefore, that this form of registration has not rapidly replaced the Geiger counter in which the primary ionization is amplified by impact ionization 10^7 times in the counter itself. This augmented ionization current is then easily handled by a very simple amplifier. Thus, once given a satisfactory counter, it is a comparatively simple matter to record the entrance of particles into the counter. However, in the counter the primary ionization serves only as a trigger to set off a much larger impact ionization which can never be more than very roughly proportional to the primary ionization.

Greinacher [1] first demonstrated that it was possible to amplify directly the primary ionization of a single particle. For this purpose he used an ionization chamber with electric field only sufficiently intense to insure rapid and complete collection of the primary ions. Later developments of this arrangement led to vacuum-tube circuits of many stages of amplification which were not only difficult to operate but risked a serious sacrifice of the linear characteristics required to make the amplifier of value.

More recently the development of amplifiers which meet the requirements of linearity and reasonable convenience of operation have been undertaken by Wynn-Williams and Ward [2] and by Leprince-Ringuet.[3] Although accomplishing the same result the two circuits differ considerably in details. Unfortunately neither circuit is readily available to investigators working in this country, since the tubes used are of foreign manufacture, therefore it is difficult to procure or to replace them, or to secure information to enable one to select from tubes available here those which would have similar characteristics. For these reasons the writer, in undertaking to construct an amplifier, was faced with the necessity of working out an arrangement based on the principles outlined by Wynn-Williams and Ward, but making use of entirely different types of tubes with the exception of the output tube. In doing this it was found possible to use commercial radio tubes in all stages except the first. The tube used here is so simple in construction that it can be made in almost any laboratory, and full details of its construction are given.

Since a complete discussion of the principles involved in the design of such circuits is given by Wynn-Williams and Ward and the theory of the operation is very adequately discussed by Ortner and Stetter,[4] these matters are not discussed here.

II. DESCRIPTION OF THE AMPLIFIER

As pointed out by Leprince-Ringuet, the essential difficulty met with in amplifying these primary ion pulses is that of conserving the small quantity of charge and converting the sudden rise in potential produced when this charge is driven on to the collecting system of the ionization chamber into a current pulse which can be readily amplified. No ordinary radio tube is suitable for this purpose, since the grid in such tube is not insulated sufficiently to deal successfully with such small quantities of charge. Since neither the tube used by Wynn-Williams and Ward nor by Leprince-Ringuet was available, the writer constructed a simple tube from the description given by Leprince-Ringuet. Figure 1 shows a sketch of this tube. It is a 3-electrode tube which departs from the usual arrangement in that the filament is located between the grid *G* and the plate *P*, the grid in this case being a plane electrode like the plate. The filament (an oxide-coated nickel ribbon operating on 0.4 ampere and 0.6 volt) is stretched parallel to the plane of these electrodes. The filament and plate leads are taken out

[1] H. Greinacher, ZS. f. Phys., vol. 36, p. 364, 1926.
[2] C. E. Wynn-Williams and F. A. B. Ward, Proc. Roy. Soc., vol. 131, p. 391, 1931.
[3] L. Leprince-Ringuet, Annales des P. T. T., vol. 20, p. 480, 1931.
[4] G. Ortner and G. Stetter, ZS. f. Phys., vol. 54, p. 449, 1929.

through a press seal at the lower end of the tube, the grid lead being brought out separately at the top. This arrangement provides for better insulation of the grid which is further increased by making the tube of pyrex glass. Other features of this tube which make it particularly suited to this work are a a low grid-ground capacity and a filament emission limited by space charge. The high insulation and low capacity of the grid, a plate about 1 cm square, make possible the rapid and sufficient rise of potential of the grid required to produce a current pulse in the plate circuit. The space-charge characteristics of this tube are of great value in cutting down the shot effect. With several succeeding stages of amplification, the shot effect becomes one of the limiting factors in the operation of the amplifier. This effect is so large in ordinary tubes that they can not be used in the first stage since the current pulses resulting from it mask entirely the pulses which come from the ionization chamber.

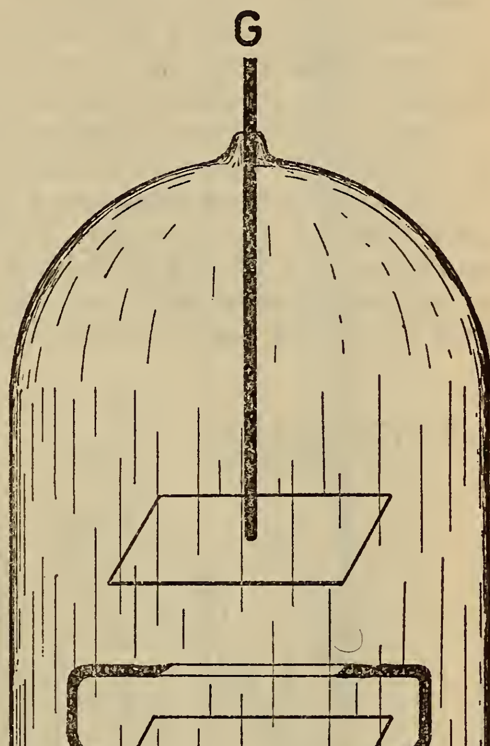

FIGURE 1.—*Diagram of special electro meter tube*

G=grid lead; *P*=plate lead

It is quite possible that other types of electrometer tubes, for example the FP54, would serve here, but the tube described is much simpler in construction and operation and likewise less expensive.

Having determined the type of tube for the input stage, the remainder of the amplifier becomes more or less routine radio practice as related to audio-frequency resistance-capacity coupled amplifiers. The complete circuit is shown in the wiring diagram reproduced in Figure 2. It has five stages, four of which use commercial radio tubes. In order to obtain as much amplification per stage as possible, thus reducing the required number of stages, screen grid alternating current amplifier tubes (type 224) were selected for the three amplifying stages. Following Wynn-Williams and Ward, a pentode was used in the output stage and the time constants of all these stages were made large. The amplifying constant of the 224 tubes connected as shown is 1,000. Naturally the amplification per stage does not attain such a high value, but with the resistances here used it is reasonable to expect an over-all amplification of about 100 per stage. This high degree of amplification is necessary since, as Leprince-Ringuet points out, the input tube does not amplify the potential applied to it. In fact, the potential surge produced at the plate end of the plate circuit resistor by the plate current of this tube is probably of the order of one one-hundredth of the rise of potential of its grid. However, this is a potential surge in a battery-fed current which can be amplified readily without unusual precautions regarding insulation.

The constants for all parts of the circuit are given below the diagram in Figure 2. Those condensers not designated by a letter are 2 microfarad by-pass condensers to shield the amplifier from extraneous pulses picked up by battery leads. Thorough shielding of the whole amplifier by a divided metal box is of course essential. The amplifier is very sensitive to high-frequency oscillations which ruin its effectiveness by setting up relaxation oscillations in the coupling condensers.

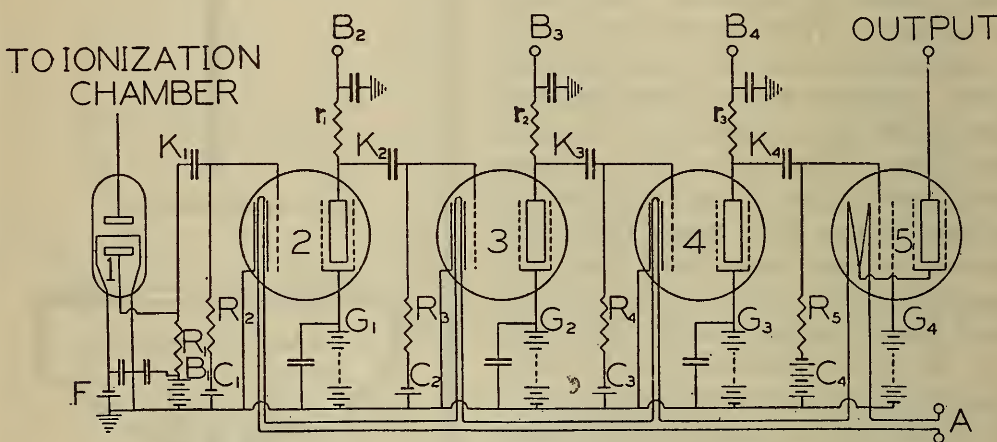

FIGURE 2.—*Wiring diagram of amplifier*

1=Electrometer tube; 2, 3, 4=224 tubes; 5=247 tube; r_1, r_2, r_3,=250,000 ohms; R_3, R_4, R_5=1 megohm- R_2=2 megohms; R_1=250,000 ohms; B_1=4.5 volts; B_2, B_3, B_4=250 volts; G_1, G_2, G_3=25 volts; G_5=250 volts C_1, C_2, C_3=1.5 volts; C_4=25 volts; K_1=0.0005 microfarad; K_2, K_3=0.1 microfarad; K_4=2 microfarad. F(fila ment battery for electrometer tube)=0.6 volt. A=10 volts (1.75 amperes). Condensers not designated are 2 microfarad by-pass condensers.

Particular note is to be taken of the coupling of the electrometer tube to the rest of the amplifier. This is the "distorting" stage mentioned by Wynn-Williams and Ward. It is very important to have the time constant of this circuit small. The value used here is 0.001 second. Since a higher value of grid leak was required than that used by Wynn-Williams and Ward, this small constant is secured by using a smaller coupling condenser (0.0005 microfarad). For some reason that does not seem self-evident, Leprince Ringuet was able to use a comparatively slow circuit at this point (0.04 second). However, he does not give a diagram of his complete circuit so that he may have introduced the "disotrtion" at a later stage. It may be well to emphasize that it is not safe to depend merely on the values of the resistances and capacities given and to construct an amplifier without testing its performance thoroughly by means of an oscillograph. This is particularly important, of course, when other forms of recording are to be used. The writer's experience indicates that only by taking careful oscillograph records can it be made certain that the amplifier is functioning properly.

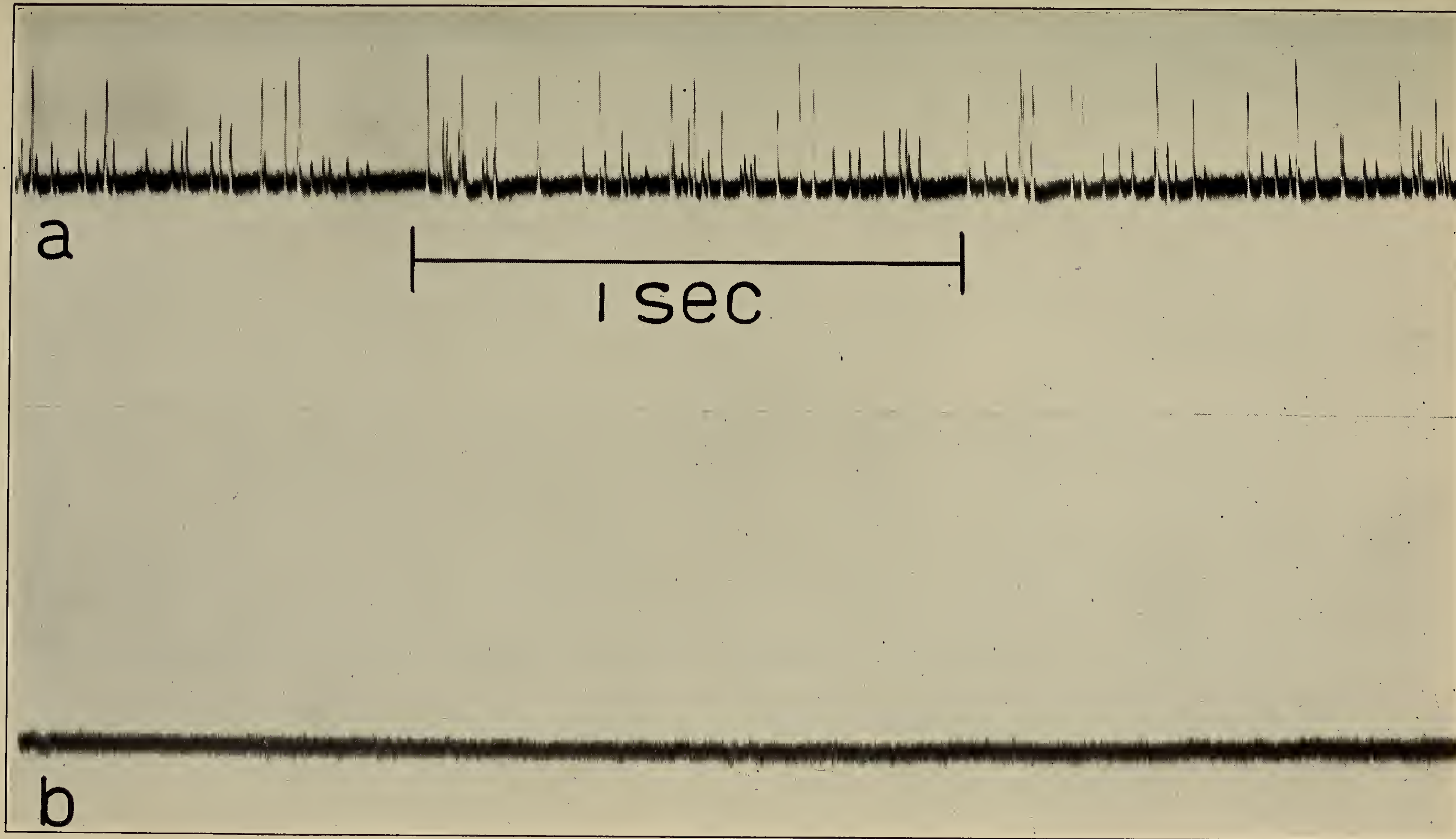

Figure 4.—*Oscillograph records*

a, *α* particles in presence of β and H particles; *b*, zero line in absence of radiation.

III. THE IONIZATION CHAMBER

Wynn-Williams and Ward describe the precautions to be taken in designing ionization chambers for use with an amplifier of this kind. The guard-ring type of chamber is particularly suited for this use, but in the form which they describe the "parasitic" capacity has not been reduced to a minimum. Their design is shown in Figure 3(*a*). The capacity of this system consists of (1) that between the window, *W*, and the electrode, *E;* (2) that of the cylindrical condenser formed between the guard ring, *G*, and the electrode, *E*; and (3) the capacity of the lead, *L*, mainly located at the point where it passes through the insulator, *S*. The capacity (1), is that of the ionization chamber itself and can not be reduced without reducing the effective volume of the chamber. The other two, however, are not associated with the volume of the chamber and any means of reducing them will increase the sensitivity of the arrangement. Of these, (2), that represented by the cylindrical condenser between the electrode, *E*,

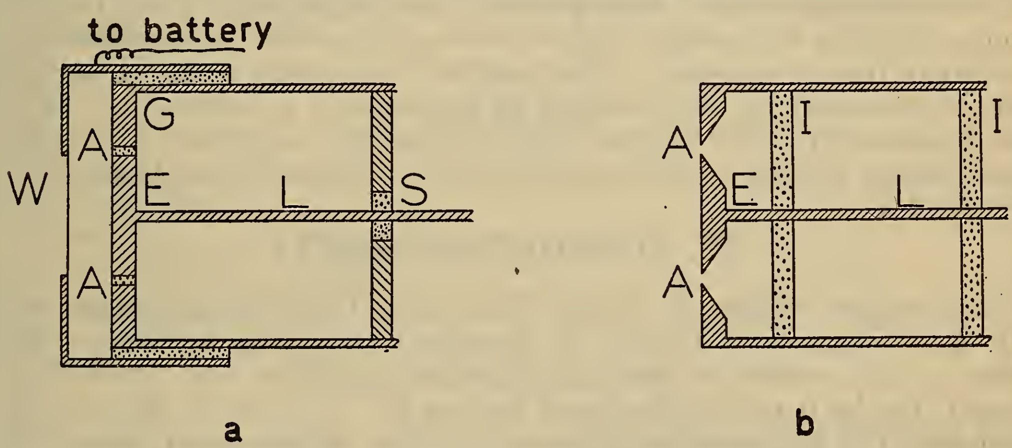

FIGURE 3.—*Section of ionization chambers*

and the guard ring, *G*, is by far the largest. In fact, it may be several times larger than the rest of the capacity of the system, particularly when, as in the chamber described by Wynn-Williams and Ward, insulating material is inserted in the annular gap to support the electrode, *E*. This difficulty may be greatly reduced by modifying the internal parts of the ionization chamber as shown in Figure 3 (*b*). The electrode, *E*, and the guard ring here have tapered edges which reduce the capacity at this point to a minimum. The insulator is removed entirely. The lead, *L*, is supported by two large insulators, *II*, at points where the capacity is a minimum. This requires the lead, *L*, to be stiffer and, therefore, of larger diameter, but the actual increase in capacity between, say, 0.5 millimeters and a 1.5-millimeter rod at this point is small compared with the reduction of capacity effected by the modification.

As examples of the kind of records that may be obtained with this amplifier and ionization chamber, reproductions of oscillograph records are shown in Figure 4 (*a*) and (*b*). Figure 4 (*a*) is a record of α particles obtained in the presence of β and H radiation and indicates the ease with which different types of radiation may be identified. Figure 4 (*b*) a blank record on the same time scale, indicates the nature of the zero line in the absence of radiation. The unsteadiness in this line is made up of a combination of effects, such as shot effect in the first tube, sound vibrations in the ionization chamber, and mechanical shock, all of which may set up small pulses in the amplifier. The ionization chamber with a thin metal window is a sensitive microphone which must be shielded as far as possible from all sound. The zero line is much less steady than that shown if reasonable precautions are not taken to shield the complete amplifier from noise and mechanical shock.

The tallest peaks in Figure 4 (*a*) are due to α particles and vary slightly in height as a result of differences in speeds and in lengths of paths of the particles as they traverse the ionization chamber in different directions. The shortest sharp peaks are produced by H particles and are roughly of one-fourth the height of the peaks due to α particles. Since a high-speed α particle produces about the same ionization as a low-speed H particle, there are some peaks of intermediate height which could not be identified merely by a study of the record. Since a β particle has only about one two-hundredth of the ionizing power of an α particle, the ionization of the β particles merge with the extraneous disturbances and can not be identified with certainty from the record. This makes it clear why α and H particles can be recorded by this method in presence of γ radiation. This is not possible with the Geiger counter since the secondary β rays produce pulses which can not readily be differentiated from those due to α particles.

IV. ACKNOWLEDGMENTS

The writer wishes to acknowledge aid from consultations with Dr. A. V. Astin and Dr. G. W. Gardiner regarding problems which arose in the course of constructing the amplifier, and from B. W. Brown for help in building and testing it. Mr. R. G. Kenedy, jr., prepared the oxide-coated filament for the electrometer tube. The writer is particularly grateful to Dr. F. West and to Dr. C. F. Burnam, of the Howard A. Kelly Hospital of Baltimore, for the material from which the polonium source used in testing the amplifier was extracted.

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